Process Safety and Environmental Protection 98 (2015) 417–423

Contents lists available at ScienceDirect

Process Safety and Environmental Protection

journal homepage: www.elsevier.com/locate/psep

Release characteristics and control of nitrogen, phosphate, organic matter from spent mushroom compost amended soil in a column experiment

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ARTICLE INFO

Article history:
Received 18 July 2015
Received in revised form 25 September 2015
Accepted 6 October 2015
Available online 22 October 2015

Keywords:
Spent mushroom compost
Column test
Nitrogen
Phosphate
Organic matter

ABSTRACT

Spent mushroom compost (SMC) is a co-product of edible mushroom which contains abundant nutrients including organics, nitrogen (N) and phosphorous (P). This study is related to the release potential of nitrogen, phosphate and organic matter from SMC amended soil in column-based experiments. Results showed that due to SMC application, NH_4^+–N and NO_3^-–N concentrations in leachate decreased by 92.5% and 76.3%, respectively, while EC and COD_{Cr} concentrations increased by 84.2% and 481.9%, respectively, as compared to chemical fertilizers. Moreover, a minor loss of TN_{cum} (65%) and TP_{cum} (almost equal value) exhibited good nutrient retention capacity. Leaching test results demonstrated that the mixed application of SMC and chemical fertilizers could alleviate excessive COD_{Cr} level in SMC leachate. The release process of nutrients in SMC amended soil could be described by first/first order mixed model, indicating that nutrients leached from SMC follow a two-stage pattern.

1. Introduction

Agricultural solid wastes, including forest residues and unutilized cellulose based industrial residues, may cause environmental problems, such as occupying vast area, dispersing stink odors, and ground water pollution (Garg and Gupta, 2009). Spent mushroom substrate (SMS), an organic waste, has traditionally been incinerated or deposited in landfills, which would further produce large amounts of greenhouse gases and occupy valuable agricultural land (Zhang and Sun, 2014). In China, more than 22.6 million tons of edible mushrooms are reported to be produced every year. Thus, a considerable amount of SMS requires proper disposal technique for minimizing its environmental effects as soon as possible. A number of reports have demonstrated the beneficial application of SMS in environmental friendly methods (Zhu et al., 2012) and most concentrated on composting treatment.

Composting is a process of biological decomposition and stabilization of wastes, which could transform organic matter into stable products (Zhang and Sun, 2014). Mushroom production has become the biggest solid-state-fermentation in the world (Soccol and Vandenberghe, 2003) and SMS derived compost, which is defined as spent mushroom compost (SMC) has turned out to be an appropriate organic fertilizer (Ribas et al., 2009). SMC contains abundant nutrients including organic substances, sulphur, potassium, calcium, magnesium, nitrogen and phosphorous (Jordan et al., 2008; Zhang and Sun, 2014). Moreover, it is generally regarded as a neutral soil amendment in agriculture production and ecosystem restoration (Chong et al., 1991; Guo, 2005). SMC will neither add a great

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http://dx.doi.org/10.1016/j.psep.2015.10.003

Table 1 – Physico-chemical characteristics of SMS/SMC.

Parameters	SMS	SMC
C (%)	32.1	15.3
H (%)	4.4	2.1
N (%)	1.7	1.1
P (%)	–	0.2
C/N	18.4	13.6
Ash (%)	14.3	12.7
Protein (mg/g)	22.4	11.2
Polysaccharide (mg/g)	9.7	2.0
Moisture (%)	42.3	41.6
pH	6.2	7.2
EC value (ds/m)	45.3	36.5
TDS (mg/L)	22.5	18.2
Lignin (%)	11.6	12.1
Cellulose (%)	29.1	29.8
Hemiscellulose (%)	7.3	7.0

amount of the macronutrients such as nitrogen, phosphorous, and potassium (N, P, K) to the soil nor tie up nutrients (Curtis and Suess, 2006).

Excessive chemical fertilizers application would cause over fertilization, which will not lead to any extra yield of grain (Zarabi and Jalali, 2012). Consequently, many researchers worldwide have reported serious NO_3^-–N pollution in surface and groundwater due to chemical fertilizers (Angelopoulos et al., 2009; Chen et al., 2007; Shomar et al., 2008). Therefore, as a slow-release source of nitrogen (Stewart et al., 1998), SMC is becoming a potential alternate for soil amendment. Recent studies have investigated the release of nutrient from SMC amended soil under laboratorial and field conditions (Stewart et al., 1997, 1998). Besides, the slow nitrogen mineralization rate from SMC and the necessary addition of inorganic-N fertilizer for rapid plant growth were also clarified in reported studies. However, no report has systematically compared the nutrients loss between chemical fertilizers and SMC.

This study was undertaken under four broad categories including: (1) Physico-chemical characteristics of SMC were studied with the objective of determining the applied rate that could contribute to soil enrichment. (2) Heavy metal content was measured to evaluate the safety of SMC application. (3) The soil columns study was performed to compare the leachate components between chemical fertilizers, SMC and mixed fertilizer. (4) Several releasing models were applied to describe the leaching characteristics of SMC amended soil.

2. Materials and methods

2.1. *Spent mushroom compost*

2.1.1. *Physical and chemical characteristics*

SMC samples were obtained from an edible mushroom Industrial Ltd., located in Qingyuan (Zhejiang, China), consisted mainly of *Pleurotus ostreatus* degraded straws. Meanwhile, raw composting material (SMS) samples were also collected for a comparative study. Both the fresh samples were air-dried under an environment without sunlight or ventilation, and crushed into granules (<2 mm) for component analysis. Selected physicochemical properties were measured before leaching experiment (Table 1). pH, EC and TDS were determined for slurry in a ratio of 1:5 (w/v) consisting of dry material: distilled water. Lignin, cellulose and hemicellulose were measured according to the Van-Soest method in Agricultural Hand Book (No. 379). Protein was measured using Coomassie light blue (Sedmak and Grossberg, 1977); Polysaccharide with phenol-sulfuric acid (Masuko et al., 2005). C, H and N contents were analyzed by a Flash EA 1112 Thermo Finnigan elemental analyzer. Total P was measured colorimetrically by UV spectrophotometry.

2.1.2. *Heavy metal content*

In order to conduct risk assessments of SMC application, heavy metal concentrations in SMC samples were analyzed by inductively coupled plasma emission spectrometry (ICP6000, Thermo Fisher Scientific). Table 2 illustrates the test outcome. Although it was not known if these contents were within acceptable range as no heavy metal limits have been standardized for SMC in China, there are limits to implement for organic fertilizer. According to the NY525-2012 organic fertilizer standard carried out in China, Cr, Cd, Pb and As contents of SMC were well within the recommended range and should not be concerned in application. Compared to the proposed legal heavy metal levels in Germany and Netherlands, Cu, Ni and Zn obtained by SMC were also significantly lower than the permissible limits.

2.2. *Leaching experiment*

The experiment was conducted using subtropical cropland soils collected in Hangzhou city, Zhejiang Province, China (30°18′20″N, 120°4′21″E) (Zhao et al., 2014; Zhao and Xing, 2009). A series of PVC columns with 10 cm diameter and 20 cm length were employed for leaching-incubation experiments. As described by Zhao et al. (2014) and Xu et al. (2012), each column was fixed with a porous baffle and pretreated quartz was loaded above the baffle. Quartz sand used in this experiment was pretreated with 1 M HCl and distilled water until the solution was neutral.

For comparison, SMC was in contrast with SMS, chemical fertilizers and compound fertilizer, respectively. Table 3 describes the treatment details. For control treatments, each column contained 600 g 2 mm-sieved soil. As typical N, P fertilizers, urea and calcium superphosphate were used to provide nitrogen and phosphate in chemical fertilizers treatment (CF). The application rates of SMS and SMC in treatments were equivalent to the application of 300 mg N/kg, which was comparable with 550–600 kg N/ha per year in an actual field (Ju et al., 2009).

After packing the column with the mixture of soil and amendments, the surface of the mixture was covered with 1 cm of quartz stone in order to make a uniform distribution of leachates. The well-packed columns were incubated at 25 °C inside an incubator throughout the whole experiment (Qian and Cai, 2007) and DI water was added to adjust the soil moisture content to 65% WHC (Water holding capacity) (Novak et al., 2009). On incubation day 1, 8, 15, 22, 29, 36, 43, and 50, respectively, 320 mL of DI water was added to the top of each column and leaching occurred through gravitational force. The total amounts of water were determined depending on the average annual rainfall recorded on Li Shui Water Resources Bulletin. The constant flow rate of DI water was controlled by a peristaltic pump. After a 60-min equilibrium time, the leachates were completely collected while all the columns were returned to the incubator to start the next cycle. We call this process a leaching event. DI water was added as a supplement of water evaporation between adjacent leaching events.